

sigma

Natural catastrophes in times of economic accumulation and climate change

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Executive summary

Global insured losses from disaster events in 2019 were USD 60 billion.

At USD 146 billion, economic losses from disaster events in 2019 were lower than in each of the previous two years, due to the absence of severe hurricanes in the US. Insurance covered USD 60 billion of the losses, below the annual average of USD 75 billion of the previous 10 years. Of last year's insured losses, USD 52 billion were due to natural catastrophes. Typhoons Hagibis and Faxai in Japan were the biggest individual loss events of 2019 anywhere in the world.

The trend of rising losses from weather events is mostly due to rising exposures on account of economic growth and urbanisation.

Since 1980, the majority of rising losses associated with weather events has been due to exposure accumulation that comes with economic growth and urbanisation. The concentration of assets (human and physical), particularly in urban areas such as low-lying coastal regions that are vulnerable to adverse weather conditions, inflates the loss potential when a severe weather event strikes. Other socio-economic factors account for most of the remainder of the trend of rising losses over time.

We expect climate change effects will increasingly show in rising losses in the coming decades.

This *sigma* includes a chapter authored by Professor Adam Sobel of Columbia University saying that while the full extent of the impact of climate change is difficult to predict, lack of proof does not prove there has been no change. Climate change effects are already showing: warmer average temperatures, rising sea levels, more frequent and longer heatwaves, greater weather extremes, and erratic rainfall patterns. We expect warmer temperatures will lead to growing frequency of severe weather events, and that these will make an increasing contribution to rising losses in the coming decades. The impacts manifest most notably in more intense secondary peril events, which are smaller to mid-sized events or the secondary effects of a primary peril. For example in 2019, the heavy rains that came with Typhoon Hagibis in Japan, the storm surge after Cyclone Idai in Mozambique, and monsoon rains in southeast Asia resulted in widespread flooding. And, while wildfires in California eased relative to 2017 and 2018, record-high temperatures in eastern Australia kept wildfires burning across millions of hectares of bushland in the longest-running wildfires the country has ever seen.

Weather-related risks remain insurable...

The full extent of the impact of climate change is complex and difficult to predict, but we believe weather-related risks remain insurable. However, the time to act is now. The long-term risk of unmitigated climate change is irreversible "tipping points" and in this scenario, climate change effects could bring the insurability of assets, particularly in regions with high exposure accumulation, into question. The industry needs to actively embed and dynamically track the effects of the warming climate, adapting models to a profoundly changing risk landscape. This entails incorporating two new dimensions into risk assessment. The first is time scale. Insurers should model for the near-, while also plan for the long-term horizon. And the second is levels of confidence, as to expected outcomes across various weather-related perils.

...but the insurance industry needs to reassess underwriting processes, and also incorporate till now unaccounted for loss components in risk modelling.

Climate change makes the risk landscape dynamic and insurers need to respond accordingly. Many of today's catastrophe models are rooted in the past. They do not fully account for rising exposure from increased value concentration in a rapidly urbanising and, at times, more vulnerable world, especially when sprawling into higher hazard regions. Other complex factors such as loss creep also present a modelling challenge. Loss creep refers to mounting losses over time, and has been visible in the loss development of major hurricane and typhoon events. There can be many contributing factors, including social inflation or lack of coordination in claims processing, which push losses up to levels higher than anticipated.

Climate change effects and other trend developments pose a risk to re/insurer profitability and solvency.

Re/insurance companies face climate-change risks on both sides of their balance sheets, which can have adverse effects on underwriting profitability and solvency in the long term. On the liability side, the main risk is underestimating insurance risk premiums due to reliance on historical loss data or incomplete/outdated models. On the asset side, the exposure derives from the impact of physical and transition risks on invested assets, including infrastructure funds and corporate bond holdings. As a first step to sustaining profitability, re/insurers need to adjust to the risk landscape of today, as represented by current climate change effects and other relevant trends.

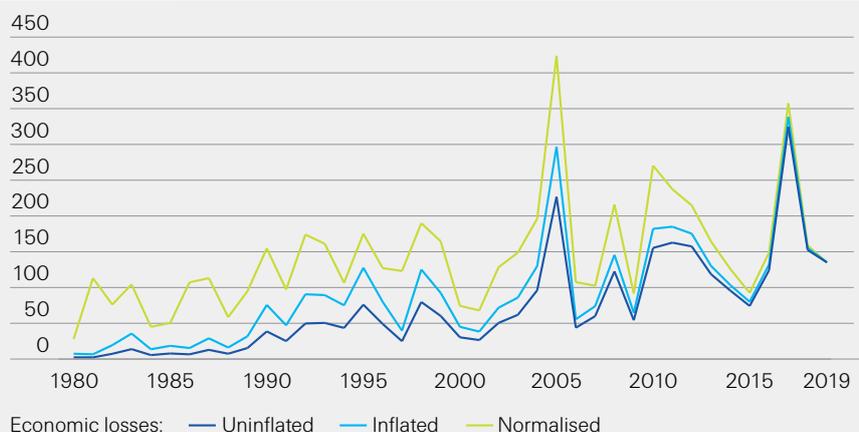
Key report takeaways

- To date, the majority of the trend of increasing losses from natural catastrophes has derived from exposure accumulation in the form of human and physical capital, which in turn has resulted from economic development and urbanisation.
- As global temperatures warm, we expect the frequency of severe weather events to increase and that these will make a growing contribution to rising losses over the coming decades.
- The effects of climate change are evident in the world today: warmer average temperatures, rising sea levels, melting ice caps, longer and more frequent heatwaves, erratic rainfall patterns and more weather extremes.
- Climate change effects show most notably in their growing contribution to losses from secondary perils. In each of 2017, 2018 and 2019, secondary perils, which can be small to mid-sized events, or secondary effects of a primary peril (eg, a tsunami after an earthquake), accounted for a lion's share of the respective years' total losses.
- The processes of how a changing climate impacts the frequency and severity of natural catastrophes are not fully understood. Signs of a climate change influence on primary perils like hurricanes are less clear, though such an influence is still likely present. The outstanding questions are its nature and magnitude, and to what extent it is affecting losses.
- All told, we believe failure to act now could lead to irreversible tipping points in climate systems, which in turn could jeopardize insurability, particularly in high-exposure accumulation areas.
- So far, weather-related risks remain insurable. The short-term nature of most property re/insurance business allows for continuous adjustments of risk views to reflect observed changes in climate, exposures and vulnerability.
- To sustain insurability, the re/insurance industry needs to dynamically track the effects of a warming climate, adapting models to an ever-evolving risk landscape, and continually embed new understandings into risk assessment.
- Key for next-generation forward-looking modelling is understanding how socio-economic factors rooted in the past, but which are currently not fully captured in models, impact rising risk and losses today.
- Further, the catastrophe events of 2019 offer lessons on complex loss components like loss creep, which are also not always fully reflected in current risk models.

Exposure accumulation and rising losses

Normalisation adjusts to show that an event in the past, if it were to occur at the same magnitude today, would cause more damage now than in the year of occurrence due to the accumulation of value (human and physical assets) in the intervening years. All else being equal, climate change would lead to growing losses over time. But socio-economic and other factors do not remain constant and by the same token, a rise in normalised losses is not "proof" of climate change.

Economic losses from extreme weather events 1980–2019: uninflated, inflated (2019 prices) and normalised (USD billion)



Source: Swiss Re Institute

How confident are you?

Modelling dynamic risks like climate change comes with many uncertainties. In the absence of hard data, the approach should be to assess risk in terms of levels of confidence as to expected changes across different weather-related perils.



Driver for change



Effects/perils



Time horizon



Insurance impact, focus on property cat

		High confidence			
Global Warming Response	Direct	Increasing mean temperature	Melting of glaciers & ice caps, thermal expansion: sea-level rise/storm surge Reduced permafrost/slope stability: landslides	Slow but steady increase over next decades	Low-medium property insurance impact: no sudden/unprecedented events (adaptation!) . Localized effects in coastal and flooding zones
	Indirect	Increasing temperature variability	Longer/more frequent heat waves, droughts, water scarcity, wildfires , health issues & increased mortality, potential political conflicts	Heat waves/droughts: already observable and increasing trends over next decades	Frequency perils , mostly affecting primary insurance, quota share and stop-loss reinsurance. Impact on insurance earnings , rather than capital. Impact strongly varies due to heterogeneous original covers, with considerable protection gap in flood insurance
		Confidence Barrier			
		Increased moisture capacity in atmosphere due to higher temperatures	More frequent extreme rainfall and river floods	Increasing regional trends already observable and medium-severe impact likely by mid/end of century	
		Impact on climate cycles (e.g. ENSO, AMO, NAO)	More frequent severe tropical cyclones Change of frequency/severity of winter storms	Severe impact likely by mid/end of century	Limited insurance impact as of today where climate risk is managed actively. Mid/end of century significant impact on re/insurance covers, both for severity (affecting capital) and frequency (affecting earnings), in particular where associated flood risk is covered in full
		Increased convection	Increased hail & tornado risk		
		Reduced confidence			

Source: Swiss Re Institute

In a nutshell: catastrophes in 2019

Total economic losses

USD 146 billion

down from USD 176 bn in 2018,
below 10-year average of USD 212 bn

USD 137 billion

of economic losses were caused by
natural catastrophes, USD 9 bn by
man-made disasters

0.17% of global GDP

below the 10-year average of 0.26 %

Total insured losses

USD 60 billion

down from USD 93 bn in 2018,
below 10-year average of USD 75 bn

USD 52 billion

of insured losses were caused by
natural catastrophes, USD 8 bn by
man-made disasters

**3.3% of global property
direct premiums written**

below the 10-year average of 4.4 %

Victims



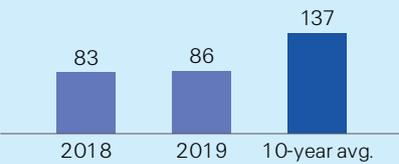
11 497

Number of catastrophe events



317

The global protection gap little changed and below average (USD bn)



Highlights

- Economic and insured losses from catastrophes in 2019 were lower than in the two previous back-to-back high-loss years.
- Weather-related events were the main contributors to the natural catastrophe losses in 2019.
- Once again, Japan was struck by severe typhoons: Typhoons Hagibis and Faxai resulted in the largest insured loss totals (USD 8 billion and USD 7 billion, respectively) of all disaster events around the world.
- Typhoon Hagibis unleashed extreme precipitation, highlighting again the growing contribution of secondary perils as loss drivers and putting typhoon induced flood risk much higher on the Japan hazard map.
- In terms of wind speed, Hurricane Dorian was the strongest of the 2019 North Atlantic season. It maintained Category 5 winds for the longest duration on record. For the Bahamas, it was the costliest natural disaster event ever.
- Cyclone Idai devastated the coastal town of Beira in Mozambique, demonstrating the exposure and vulnerability of many low-lying cities to extreme precipitation and storm-surge induced flooding.
- 2019 was the second warmest year, and 2010–2019 the warmest decade on record.
- After record-highs in both 2017 and 2018, wildfire losses were lower in 2019. While there was less wildfire activity in California, record high temperatures and precipitation deficit triggered extensive and long-lasting burning in Australia, the country's most destructive on record.

Weather disaster losses rise as economies grow and climate changes

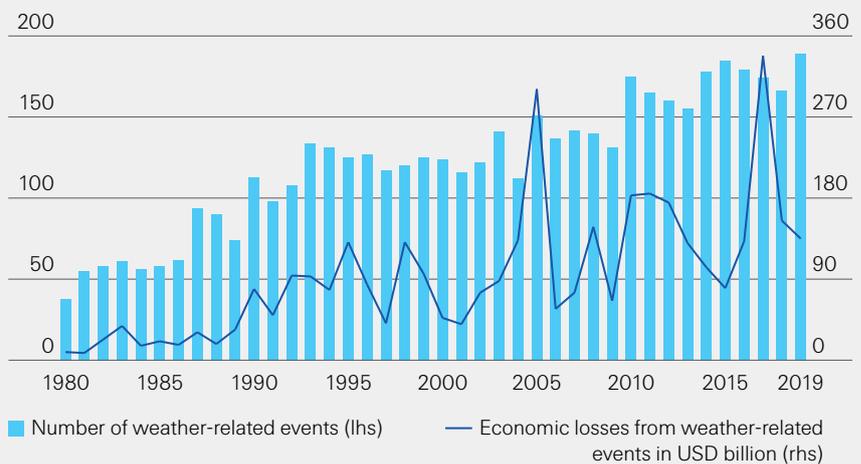
Various factors influence the scale of losses inflicted by weather events. Since 1980, exposure accumulation due to economic growth and urbanisation has been the main driver of the increase in associated losses. Normalised losses accounting for GDP growth and inflation further confirm the trend of rising losses resulting from weather-related events. We expect that climate change effects will play an increasing role in the next decades. However, with a lack of granular data on the many contributing components, including socio-economic factors, attribution modelling remains work in progress.

Economic losses resulting from weather-related events have been trending higher over time.

Economic growth and urbanisation: key exposure drivers

Both the number of and economic losses from storms, floods and other extreme weather-related events have risen significantly over recent decades (see Figure 2). The trend of rising losses has been more evident since the mid-1990s, with improved data from more comprehensive and inclusive reporting of events likely contributing. Conversely, the less noticeable gains in losses in the 1980s can in part be explained by the lesser availability of data.

Figure 2
Number of weather-related events and associated economic losses, 1970-2019 (USD billion, 2019 prices)



Source: Swiss Re Institute

Exposure growth has been the main driver of rising losses.

There are many underlying drivers to the rising losses resulting from weather-related events. The main factor is growing exposures as the world's population continues to rise and, with economic growth, urbanisation and asset values increase. Over the last 60 years, the world's population has grown by approximately 2.5-times,¹ and global real gross domestic product (GDP) by more than sevenfold.² Urban areas comprise the highest concentration of people and assets. In the 1950s, around 30% of the global population lived in urban areas. Today more than 50% does, and this is forecast to rise to near 70% by 2050.³

The three main components of disaster risk are hazard, exposure and vulnerability.

Three main components determine the impact of weather-related risks: hazard or type of peril (hurricane, flood etc); exposure, which refers to the populations and assets that lie in the path of weather-related hazards; and vulnerability (the susceptibility of the exposed elements to the hazards). Figure 3 outlines the complex interplay between the physical and socio-economic components of the weather-related risk equation. Weather-related hazard occurrence is dependent on climate conditions, changes in which are largely due to natural variability. Of late there has

¹ *World Population Prospects: The 2019 Revision*, United Nations Department of Economic and Social Affairs, 2019.

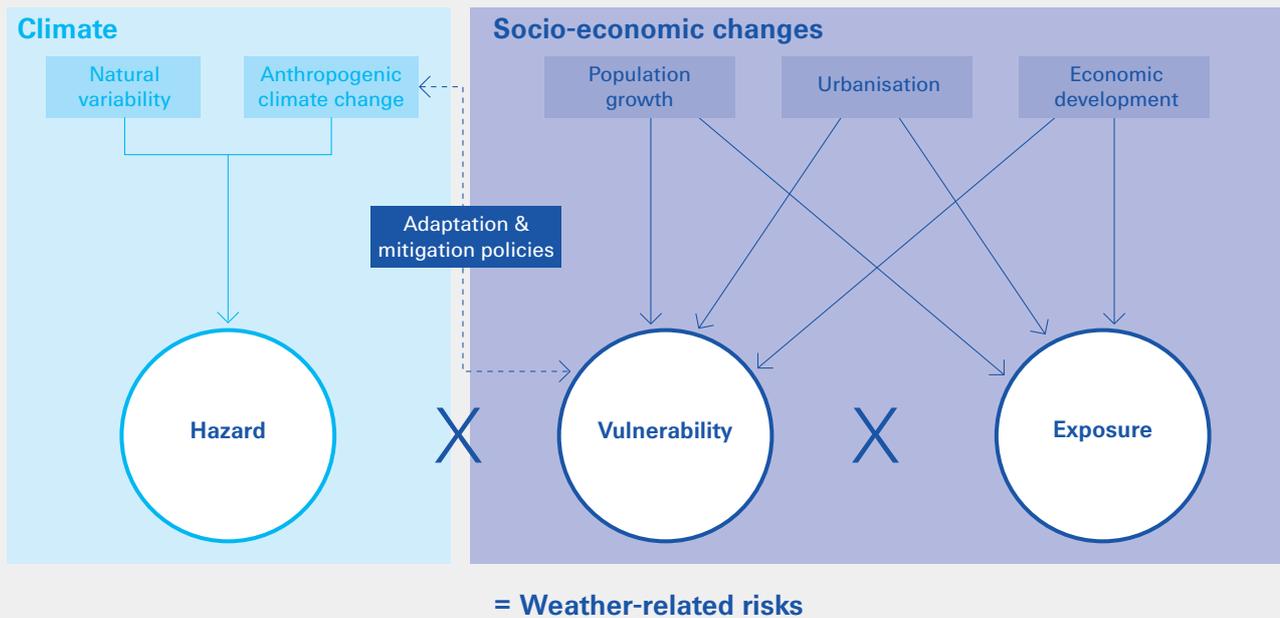
² *GDP data* from the World Bank.

³ *Urbanization Prospects: The 2018 Revision*, United Nations Department of Economic and Social Affairs, 2018.

Weather disaster losses rise as economies grow and climate changes

been growing focus on anthropogenic (human-induced) influence on climate conditions, and also the contribution of global warming to growing frequency and severity of weather-related risk events.

Figure 3
Contributing factors of the three main components of weather-related risk



Source: Swiss Re Institute

There are many drivers of weather-related risks.

There are many socio-economic components of the weather-related risk equation. Factors to consider in addition to population growth, economic development and urbanisation include human-induced changes to land use, deforestation and soil degradation. These can all further increase the impact of weather-related risks, both in terms of physical damage inflicted and size of associated losses. Population growth in areas of high hazard exposure, often coupled with lack of risk-mitigation infrastructure, further elevate the risks.

Decomposing the socio-economic factors

Exposures change over time. To disentangle the different contributing factors to rising losses, a system of metrics for exposure is required. For illustrative purpose, Table 1 lists different socio-economic factors that could be contributing components to rising losses, alongside their respective indicating metric and trends.

Table 1
Socio-economic factors driving exposure growth

Socio-economic factor	Metric	Trend
Economic development: a general, broad proxy for exposure growth.	GDP growth	Advanced economies: 2.1% Emerging economies: 4.7% (1990–2019)
Physical capital accumulation, which can exceed economic activity over time.	Capital stock or tangible assets Average cost of construction	Example: The value of tangible commercial assets and residential buildings in the US grew by 0.7% to 1.2% faster per year than GDP (1980–2003)
Urbanisation creates highly concentrated areas that require complex infrastructure.	% of population living in urban zones	68% of the world population projected to live in urban areas by 2050 with close to 90% of this increase taking place in Asia and Africa
Development of marginal land, migration to high-exposure areas.	Population growth, or new construction in highly exposed areas (eg, flood zones, coastal areas, wildland-urban interface)	Eg: In emerging economies, the population in flood-exposed low-elevation coastal zones grows about 1% faster than the overall population. Eg: Between 1990 and 2010, the number of houses in the US WUI grew by 41%.

Source: *Survey of Current Business*, US Bureau of Economic Analysis, April 2005; Neumann, B., et al. *Future coastal population growth and exposure to sea-level rise and coastal flooding—a global assessment*, 2005; *World Population Prospects: The 2019 Revision*, United Nations Department of Economic and Social Affairs, 2019; V. C. Radeloff et al., "Rapid growth of the US wildland-urban interface raises wildfire risk", *Proceedings of the National Academy of Sciences*, vol 115, no 13, 2018; Swiss Re Institute.

Growth and urbanisation account for the majority of the rise in economic losses resulting from weather-related events since 1980.

To show the impact of development and urbanisation on weather-related economic loss growth over time, we consider the period 1980–2019. In these near-four decades, average annual global GDP grew by 2.8%. To better proxy the exposure increase, we use capital rather than GDP growth as the metric. This is because if an asset is destroyed in a disaster event, the loss in value of that capital would not be directly captured in GDP readings. In 1980–2019, global capital grew by 3.9% on average each year, while global economic losses resulting from weather-related events grew by 7.1% annually. Taking capital as proxy, we estimate that economic growth and urbanisation account for a 55% share of growth in economic losses over the period, the inference being that 45% is down to additional socio-economic factors and other components (including climate change). For the emerging economies, the same methodology yields a more dramatic estimate, with economic growth and urbanisation the driving force of at least 70% of the 8% annual growth in economic losses from weather-related events over the same period.

Weather disaster losses rise as economies grow and climate changes

Urbanisation puts more people and assets at risk...

While proximity of people sparks enterprise and innovation, it also amplifies the loss potential from weather events by increasing the number of people and assets exposed, particularly when risk mitigation measures do not keep pace with the rise in value accumulation. For example, even small changes in rainfall intensity can lead to strong increases in flood damage in urban areas, because the sealing of surfaces in cities increases the risk of damage from water run-off. If a natural catastrophe hits an urban centre, the resulting losses can be many times larger than for populations more homogeneously distributed over a greater geographical area would collectively experience. We estimate that if population density increases by 1 percentage point, economic losses per capita go up by 1.2%.⁴

...particularly when urban areas sprawl into high risk areas like low-lying coastal regions and WUI.

In addition, many population centres have developed in coastal areas susceptible to tropical cyclones, storm surges and heavy precipitation. Globally, since 2000 the number of people living in the low-elevation coastal zone which are exposed to storm surge events has grown by about 1.3% annually, or 0.8% faster than the overall population. The population growth in such areas has been particularly notable in Asia and Africa.⁵ Similarly, between 1990 and 2010, the number of houses in the wildland-urban interface (WUI) areas of the US susceptible to wildfires grew by 41%,⁶ with 60% of new homes built there.⁷

Normalised economic losses have also grown over the same period...

To reflect that socio-economic factors change over time, we have attempted to "normalise" past losses resulting from weather-related events. Normalisation adjusts to show that an event in the past, if it were to occur at equal magnitude today, would cause more damage than in the year of occurrence due to value accumulation. A common approach is to apply real GDP and inflation factors to past economic losses.⁸ Using this approach, we estimate that the annual growth rate of normalised losses from global weather events between 1980 and 2019 was around 4%, still increasing but at much slower rate than shown by uninflated losses (10.9%) and also real (adjusted for inflation) losses (7.7%) over the same time period.

⁴ Based on the methodology from Schumacher, I., & Strobl, E. "Economic development and losses due to natural disasters: The role of hazard exposure", *Ecological Economics*, 72, 2011. We ran a Tobit model of economic losses per capita on GDP per capita, population density and country's surface with a country panel data set for 1980 to 2019.

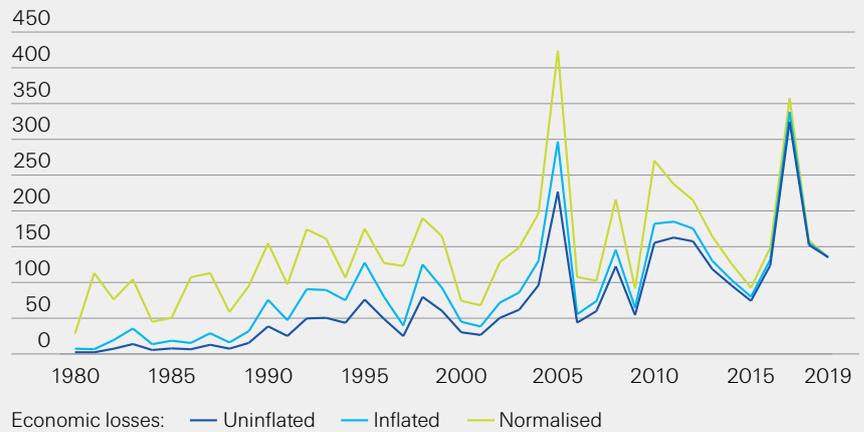
⁵ Neumann, B. et al. "Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment", *PLoS one*, vol 10, no 3, 2015.

⁶ V. C. Radeloff et al., "Rapid growth of the US wildland-urban interface raises wildfire risk", *Proceedings of the National Academy of Sciences*, vol 115, no 13, 2018.

⁷ *Wildfire, Wildlands, and People: Understanding and Preparing for Wildfire in the Wildland Urban Interface*, United States Department of Agriculture, January 2013.

⁸ Country specific GDP (countries of loss occurrence).

Figure 4
Uninflated, inflated (2019 prices) and normalised economic losses from extreme weather events, 1980–2019, (USD billion)

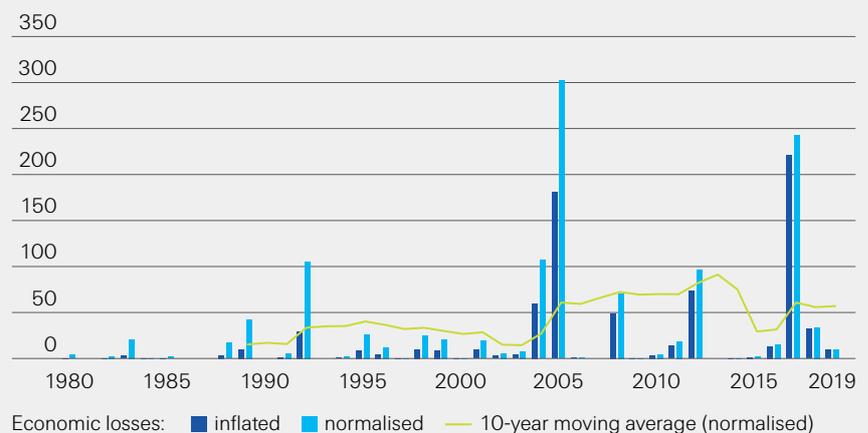


Source: Swiss Re Institute

...although the results of normalisation analysis depend on the chosen method and quality of data.

The results of this exercise depend on the chosen method and data availability, both on the socio-economic factors and on the loss side. The devil is in the (data) details: the more global the scope, the less granular the data, and the less ambitious the analysis can be. Equally, the longer the observational period, the more assumptions need to be made. For example, a study on hurricane losses in the US for the period 1900–2017 using county housing units, real wealth per country unit and inflation did not show a noticeable increase in normalised losses over the extended period, although with signs of a slight increase from the 1980s.⁹ Taking a shorter time period, 1980 to 2019, our own normalisation analysis of sigma loss data, based on real GDP and inflation only, shows a similar uptick in normalised losses from US hurricanes (Figure 5). However, many uncertainties due to lack of data granularity and limitations in methodology on account of not being able to factor in all influences remain: any such analysis is still in its infancy.

Figure 5
Inflated and normalised US hurricane losses from, 1980–2019, (USD billion, 2019 prices)



Source: Swiss Re Institute

⁹ J. Weinkle et al "Normalised hurricane damage in the continental United States 1900–2017", *Nature Sustainability*, 2018.

Weather disaster losses rise as economies grow and climate changes

Advanced normalisation requires more granular data.

More advanced normalisation should take into account socio-economic factors at a more granular level, such as evolving vulnerability and increases in capital stock. Currently, modelling the impact of socio-economic factors on losses from weather events can be done more granularly for single events only. For example, we modelled what would happen if an event like Hurricane Andrew in 1992 were to hit South Florida today, with an identical track and intensity. Accounting for increased asset exposures, we estimate that the original (in 1992) economic loss amount of USD 23 billion,¹⁰ would be USD 80–100 billion today. Even here though, large uncertainties remain due to the lack of insights in all contributing components.

With economic growth and rising incomes, per capita spending on insurance increases, to a certain level.

Insured losses

With growing exposures due to economic development and urbanisation, insured losses resulting from natural catastrophes have also risen over time. This reflects increasing insurance penetration rates (premiums as a percentage of GDP) in different countries. As people become wealthier, they acquire more assets that they want to insure against unexpected losses. At the aggregate level, according to *sigma* data, insurance penetration in advanced markets rose from 3.3% in 1990 to 3.5% in 2018. The increase in emerging markets is more dramatic, from 0.3% in 1990 to 1.5% in 2018. As per S-curve analysis,¹¹ which indicates that insurance spending accelerates in countries where GDP per capita rises from lower to middle-income status, the spending rises fastest in countries where GDP per capita ranges from USD 5 000 to USD 35 000. The rapid growth of economies in emerging Asia in recent years in particular, has moved many countries to the accelerating insurance penetration section of the S-curve.

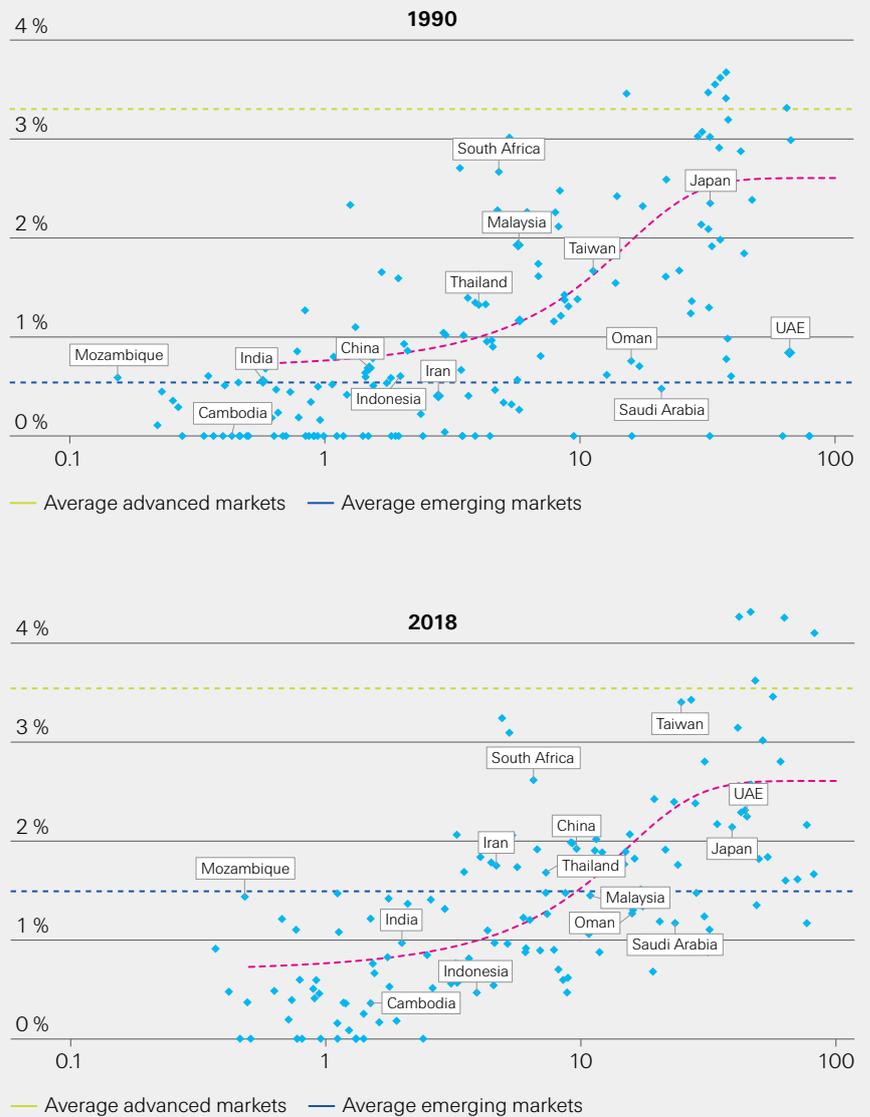
Emerging economies rise faster along the S-curve, indicating increasing insurance penetration.

Figure 6 shows non-life insurance penetration rate developments in a number of emerging economies between 1990 and 2018. The figures show that China has moved very fast along the accelerating section of the S-curve, with GDP per capita rising from USD 880 in 1990 to USD 9 620 in 2018. Thailand and Malaysia are other examples of progression along the curve. With growth in emerging Asia set to remain strong, we anticipate further increases in penetration in the coming years.

¹⁰ *Hurricane Andrew: The 20 miles that saved Miami*, Swiss Re, 9 August 2017.

¹¹ R. Enz, "The S-Curve Relation Between Per-Capita Income and Insurance Penetration", *The Geneva Papers on Risk and Insurance*, vol 25, 2000.

Figure 6
 Non-life S-curve 1990 and 2018,
 showing non-life insurance
 penetration (premiums as a %
 of GDP), GDP per capita (log scale)



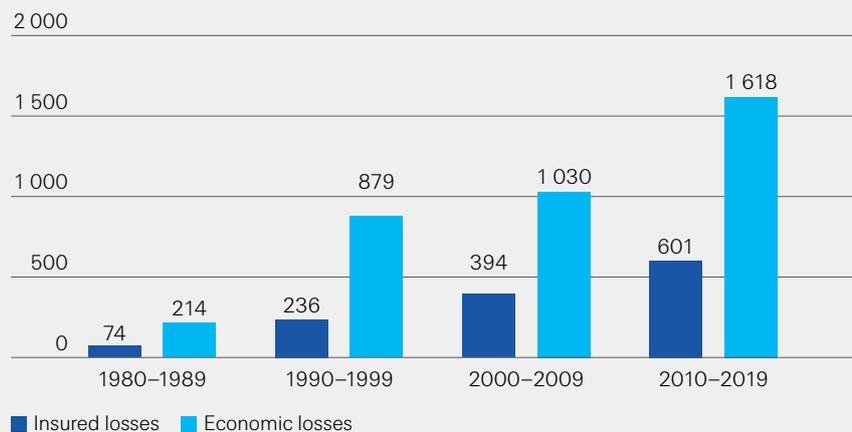
Source: Swiss Re Institute

Weather disaster losses rise as economies grow and climate changes

Even so, protection gaps, and insurance opportunities, remain.

Nevertheless, economic losses have outpaced insured losses. Figure 7 compares the real (adjusted for inflation) growth in global economic losses resulting from weather-related events with associated insured losses over the period 1980 to 2019. As shown, the protection gap, that is the difference between insured and total losses, has widened over time in absolute terms, but has reduced in proportion. This highlights the ongoing under-insurance of society even with growth in penetration. It also points to the still large insurance opportunity to fill the gap and build resilience.

Figure 7
Global economic versus insured losses resulting from weather-related catastrophes, 1980–2019, (USD billion, 2019 prices)



Source: Swiss Re Institute

Rising temperatures are altering the physical risk landscape.

Climate change and rising losses: work in progress

With global temperatures warming, we expect that hazard intensification will likely play a greater role in increasing the economic losses resulting from weather-related events in the decades to come. After remaining relatively stable for approximately 12 000 years – corresponding to the full duration of human civilization – the climate is changing, with temperatures now 1.0°C above pre-industrial times. Most physical processes that define our climate and its extremes depend directly or indirectly on the temperature of the atmosphere and the oceans. Hence, any change in global temperatures and their extremes, whether from greenhouse-gas emissions or due to natural variability, will alter the risks that humans and the world are exposed to.

Climate change effects manifest most notably in secondary peril events.

In parts of the world, some secondary-peril events such as drought, wildfire and floods have and will continue to become more extreme, due to ever-drier weather conditions, increases in precipitation and rising sea levels. For some secondary perils like heatwaves, observations, physical theories and numerical models all converge to show an increase in both frequency and intensity in most parts of the world. The effects are also feeding through to higher insurance losses on account of property damage, crop shortfalls, business interruption claims and others.¹²

¹² *sigma* 2/2019: Secondary perils on the front line, Swiss Re Institute.

There have also been some signs that climate change may impact primary peril risks.

To date the industry has successfully managed weather risk, with the help of state-of-the-art risk models....

... but greater understanding of the combined effects of a changing climate and human activities remains work in progress.

There are also signs that climate change may be impacting peak hazards like tropical cyclone risk in the North Atlantic. For instance, two of the three record loss years for the global insurance industry were due to hurricane losses in the US (2005 and 2017). And these years were not even the worst-case scenarios. A repeat of a storm similar to the Great Miami Hurricane of 1926 could, under 2017s conditions, cause insured losses of up to USD 120 billion.¹³ In terms of full-year accumulation, annual insured losses could mount to more than USD 250 billion.¹⁴

The insurance industry has a long track record of managing weather risk in the form of cyclones, storms and floods, also in a changing environment. From the mid-1990s, the industry has increasingly relied on state-of-the-art catastrophe modelling techniques to manage growing exposures. Climate change effects serve as a wake-up call that such models need continuous updates, at an accelerated pace.

To ascertain if a specific weather event is made more likely or more severe because of climate change remains challenging, however, given the many different contributing components, including socio-economic developments. More efforts are needed to arrive at a comprehensive approach that includes attributable quantification of changes in hazard, exposure and vulnerability, as well as adaptation policies. While availability of granular data remains scarce, and methodologies to fully account for all contributing factors on a global scale are still limited, the discipline of attribution research remains work in progress.

Climate change is a systemic risk for the global economy.

Failure to adapt could be very costly, particularly for poorer countries.

Climate change: it's not good for the economy either

Climate change is a systemic risk that impacts the global economy and the financial system. In 2015, an estimated USD 4.2–13.8 trillion of the world's financial assets were at risk from the impact of climate change.¹⁵ Calls to address climate risk by building a robust green financial system are becoming ever louder. According to the OECD, if a "decisive transition" to a low-carbon economy is effectively implemented, climate-change associated damage to economic value will be reduced to the tune of 2% of the GDP of the G20 nations.¹⁶ It will also boost long-run output by up to 2.8% by 2050, resulting in a net growth benefit of 4.7% across those countries. Driving this value creation will be investments in sustainable infrastructure, supportive fiscal initiatives, structural reforms and green innovation, like a capital market for green securities.

Failing to adjust could be very costly. Although academic research around the macroeconomic impacts of climate change finds only moderate impact on the level of GDP by 2100 for even more severe levels of temperature changes, the underlying models face a number of recognised limitations. Even newer panel-data frameworks still utilise historical data through today to make forward-looking predictions for temperature-GDP scenarios not seen before on a human timescale and, as such, they too are likely to be biased to the downside.¹⁷ Broader research on nature-related economic risks shows that more than half of the world's total GDP is "moderately or highly dependent on nature and its services, and therefore exposed to risks from nature loss."¹⁸ Similarly, case-study based analysis of local effects shows a

¹³ Swiss Re, 9 August 2017, op. cit.

¹⁴ Such scenarios involve at least one Category 5 hurricane making landfall at a major metropolitan centre like Houston, Miami or New York, with additional severe events in the US, the Caribbean or Mexico in the same season

¹⁵ B. Gardner, "The cost of inaction: Recognising the value at risk from climate change", *The Economist Intelligence Unit*, 24 July 2015.

¹⁶ *Investing in Climate, Investing in Growth*, OECD Publishing, Paris, 2017.

¹⁷ D. Mackie and J. Murray, *Risky business: the climate and the macroeconomy*, J.P.Morgan Economic Research Special Report, 14 January 2020.

¹⁸ *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy* World Economic Forum in collaboration with PwC, 2020.

Weather disaster losses rise as economies grow and climate changes

Economic and insurance market models do not explicitly take climate change risks into account.

Given their exposures to both physical and transition risks, insurers have an inherent interest to better understand the longer-term impacts.

potentially much more severe economic impact.¹⁹ Importantly, climate risks are not evenly distributed across geographies. They depend on the geographical setting and the sectoral composition of the economy. The largest negative effects are expected to unfold in relatively poor countries that may be unable to afford significant adaptation and/or mitigation costs.²⁰

Despite the increasingly recognised effect on economic development, climate risks are not explicitly taken into account in longer-term mainstream economic and insurance market models. A key reason is because it is conceptually and computationally difficult to estimate the magnitude of climate risks across multiple dimensions. Still, not taking climate developments explicitly into account is not an option for the insurance industry even if the uncertainty around estimates is large.

The insurance industry has fundamental exposure to climate risks through physical and transition risks. Physical risks are actual climate change effects, such as the secondary-effects of primary perils (eg, storm surge as a result of a hurricane). Transition risks include policy changes, reputational impacts, and shifts in market preferences, norms and technology, as the world moves towards a zero-carbon economy. The exposures mean the industry has an inherent interest to better understand the longer-term impact on the asset and underwriting sides of the balance sheet.

¹⁹ *Climate risk and response. Physical hazards and socioeconomic impacts*, McKinsey Global Institute, 2020.

²⁰ J. Nixon, *The economic impact of global warming*, Oxford Economics White Paper, 2019.

Climate change: the scientists' view

Swiss Re Institute thanks Professor Adam Sobel of Columbia University as the main author of this chapter

The way increasing temperatures change natural catastrophe risks are not fully understood. A main reason for uncertainty is a short and inconclusive history of observations of possible climate change effects, such as more intense secondary-peril effects (like storm surge) of primary perils (like hurricanes). However, signals of the effects of warming temperatures are there. It could take decades to gather hard proof points, by which time the risks posed by primary and secondary perils could well increase to levels well beyond current natural variability.

No proof does not prove no change

Professor Adam Sobel

There is general acceptance of the science behind global warming and the role of greenhouse gases.

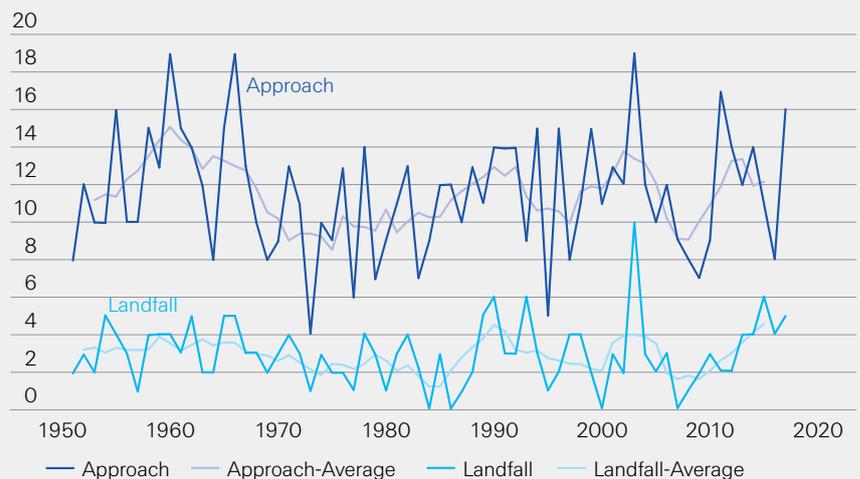
The criteria that climate scientists apply for detecting and attributing trends has been conservative.

For the scientific community, the impact of human activity on climate has now been thoroughly established. The Intergovernmental Panel on Climate Change (IPCC) estimates that human activity has caused global temperatures to increase by around 1.0°C from pre-industrial times.²¹ The IPCC further says that business-as-usual carbon emissions will likely lead to global warming of 1.5°C from pre-industrial times between 2030 and 2052, and that without action, temperatures at the end of the 21st century will be more than 4°C higher than pre-industrial norms.

Full understanding of human-induced climate change and the impact on natural catastrophe risks is still lacking. One reason is that the criteria for detecting and attributing trends that climate scientists have traditionally applied are conservative, designed to minimise the chance of "false alarm", that is declaring change when there is none. In doing so, however, the criteria raises the probability of failing to detect a change even when there is one, and this error potential is of much greater concern. For instance, it could lead insurance models predicting the likelihood of typhoons to underplay the threat posed because of the short history of observations and the infrequent occurrence, historically, of these extreme weather events. This at a time when, some may argue, human-induced climate change has led to increased frequency of typhoon events in Japan. While it is difficult to draw firm conclusions about long-term trends, typhoon activity in Japan in recent years indicates that we might be in a high-activity phase like in the 1960s (see Figure 8).

Figure 8

Tropical cyclones with maximum wind speeds of more than 34kt approaching (dark blue) and making landfall in Japan (light blue), 1951 to 2018



Note: The thick and thin lines represent annual and five-year running means, respectively.
Source: JMA Climate Monitoring, 2018

²¹ Global Warming of 1.5°C, IPCC, October 2018.

The potential for climate change to impact hurricane risk is most apparent in the growing magnitude of flooding resulting from accompanying storm surges and precipitation.

Winds are also showing signs of climate-change influence.

However, many aspects remain uncertain.

Hurricane risk: a case study for anthropogenic climate change

To make the case for human-induced impact on climate change, we focus on hurricanes, the largest contributors to global natural catastrophe losses in two of the three peak loss years on *sigma* records (2005 and 2017). There is not enough evidence to conclude with confidence that changes in hurricane activity have occurred due to rising temperatures. However, there are signals that the risks posed by hurricanes have increased, and the increased exposures could in part be due to human activity.

- **Storm surge-driven coastal flooding as a side-effect of hurricanes.** Coastal flooding events are becoming more extreme due to sea level rise. For example, the sea level in New York City has risen by about a foot since 1900, of which about 8 inches is related to the warming climate.²² For any given combination of storm and tides, flooding is exacerbated by that amount. The flooding that Hurricane Sandy in 2012 produced was due to 9 feet of storm surge, and a high tide that was 5 feet above low tide. Though small in relation to the whole storm surge, the 8 inches of additional water was still significant.
- **There is a high degree of confidence that the rainfall hurricanes produce is increasing.** Rain-driven flooding from storms such as Harvey (2017) and Florence (2018) is becoming more severe, with precipitation increasing by between 5% and 20% per 1°C of warming.²³

In addition to these secondary effects, there are also indications that the strength of hurricane winds is increasing due to climate change, and some evidence that their speed of forward motion is decreasing.

- **Hurricane winds are strengthening.** The evidence is particularly strong in North Atlantic hurricanes. The magnitude of increased wind intensity that can be attributed to warming is not clear. It may only be a few percent, but even that is significant. Damage is proportional to wind speed cubed (or perhaps more).²⁴ For any increase in wind intensity, the damage can be three or more times greater.
- **Forward motion of storms may be slowing.** Several recent studies show that the translation speed of storms has been decreasing, and suggest that this is a consequence of climate change. In the case of Hurricane Harvey (2017) and also Dorian in the Bahamas (2019), damage inflicted was made worse by the slow forward motion of the storm.

Other aspects remain highly uncertain, limiting our ability to assess overall hurricane risk in a changing climate. For example, we lack theory on how hurricane frequency will change as the climate warms.²⁵ We do not even have a good understanding of what controls the overall number of tropical cyclones presently. Historically, numerical simulations have tended to show that frequency declines with warming but in the last few years, some advanced models have instead produced increases. If storms produce stronger winds, heavier rains and more coastal flooding, but the total number of storms declines, the total hazard – the probability of an event of a given magnitude at any given location – might remain constant or even fall. But if the number of storms increases, and so too does the intensity of accompanying wind and rainfall, the risk posed would be much higher. Considering all the evidence, then, with hurricanes the situation is complex. Some aspects are becoming worse with warming; others are likely becoming worse, but with some uncertainty; and other

²² V. M. Gornitz, M. Oppenheimer, R. Kopp et al. "Chapter 3: Sea Level Rise", in *New York City Panel on Climate Change, 2019 Report*, The New York Academy of Sciences, 15 March 2019.

²³ M. Liu, G.A. Vecchi, J.A. Smith, T.R. Knutson, "Causes of large projected increases in hurricane precipitation rates with global warming," *npj Climate and Atmospheric Science*, vol 2, 2019.

²⁴ K. Emanuel, "Global warming effects on US hurricane damage", *Weather, Climate, and Society*, vol 3, no 4, 2011.

²⁵ K. J. E. Walsh et al., "Tropical cyclones and climate change", *WIREs Climate Change*, vol 7, 2016.

The interplay between natural variability and man-made climate change limits our ability to detect a signal.

Investigations continue...

...but more needs to be done.

aspects – most importantly hurricane frequency – are very uncertain. This results in large uncertainties in the overall assessment of hurricane risk.

A main issue is the just short history of observational records. This accounts for much of the uncertainty around changes in extreme weather, particularly given the existence of large natural variability. Human-induced climate change effects are superimposed on natural fluctuations, and it is difficult to separate out the human component. With extreme events, because of their rare occurrence, the fluctuations are even larger, making the statistics even less conclusive.

An additional complication is that the interpretation of important signals in the observational record of the earth's recent historical climate, and in particular some of those most directly relevant to hurricanes, is problematic. This is because it is unclear to what extent these signals represent natural variability vs human-induced change:

- **Atlantic multi-decadal variability.** This manifested notably with a recorded period of low hurricane activity in the 1970s and 1980s followed by an active period. The multi-decadal variability has long been seen as caused by natural fluctuations in the ocean's thermohaline circulation.²⁶ Later studies, however, challenge this interpretation, providing a strong case that much of the more recent variability has been due to a combination of aerosol and greenhouse gas emissions.²⁷ If this is correct, it implies a return to the inactive phase of 1970s and 1980s is less likely than would otherwise be the case, as the inactive period was caused by anthropogenic aerosol cooling which is unlikely to return (ended by environmental regulations).
- **El Niño and La Niña.** In the Pacific, historically El Niño events have suppressed hurricane activity in the Atlantic while La Niña events have enhanced it. Research, however, provides substantial evidence that the future will be more La Niña-like,²⁸ thus making the Atlantic more hurricane-prone.

Future research challenges

More research is necessary to be able to more accurately detect and attribute changes in extreme weather events to human-induced climate change.

- **Sustained observations:** The observational network must be sustained over time to maintain the long-term records necessary to document climate change, including its manifestation in extreme events.
- **Improve understanding of the physics:** Fundamental understanding of the relationship between natural climate variability (as well as of human-caused changes) and extreme weather events must improve, to increase confidence in interpretations of observations and models. In the case of hurricanes, there is still no plausible physical theory to explain the number of hurricanes each year and how that could change.

²⁶ As opposed to wind-driven currents and tides, the thermohaline circulation is driven by density differences. Sea water density depends on temperature and salinity.

²⁷ M.E. Mann and K.A. Emanuel, "Atlantic hurricane trends linked to climate change", *Eos*, vol 87, 2006; A. Clement et al., "The Atlantic Multidecadal Oscillation without a role for ocean circulation", *Science*, vol 350, 2015; K. Bellomo et al., "Historical Forcings as Main Drivers of the Atlantic Multidecadal Oscillation in the CESM Large Ensemble", *Climate Dynamics*, 2017.

²⁸ R. Seager et al., "Strengthening tropical Pacific zonal sea surface temperature gradient consistent with rising greenhouse gases", *Nature Climate Change*, 2019.

Tipping points are irreversible changes that can alter the climate system for centuries.

The most significant tipping points are the collapse of Antarctic and Greenland ice sheets...

...and dieback of the Amazon and boreal forests.

The time to act is now.

Long-term outlook: climate feedbacks and tipping points

The long-term risk of unmitigated climate change is irreversible "tipping points". The climate system comprises many dynamic oceanic and atmospheric processes, strongly interlinked and not necessarily self-stabilising. Even relatively small perturbations can "tip" the climate into a new state or initiate self-amplifying feedback loops, which in turn can significantly alter the climate for centuries to come. Examples of reinforcing (ie, positive) feedback loops include:

- **Permafrost thaw** in the Arctic due to global warming, releasing huge quantities of carbon dioxide and methane currently stored in the frozen soil.²⁹ The release of these greenhouse gases will cause more warming and more permafrost thawing.
- **Increase in wildfire activity** caused by higher temperatures and drier conditions.³⁰ The increased frequency of wildfires leads to the release of more carbon into the atmosphere, which again exacerbates the problem of global warming by effectively turning carbon sinks into carbon sources.

Several studies have identified major tipping points that could potentially be crossed either by directly forcing them (anthropogenic emissions) or by triggering positive feedbacks leading to irreversible change. Among the most significant are the collapse of Antarctic and Greenland ice sheets, the thawing of arctic permafrost, an amplitude increase in El Niño – Southern Oscillation (ENSO), a shutdown of Atlantic thermohaline circulation (eg, Gulf Stream), and shifts in monsoon patterns.³¹ All would dramatically change the global risk landscape. For example, in the case of the breakdown and melting of the West Antarctic ice sheet, studies estimate this could lead to an additional 5m rise in sea-level, while ice sheet melting in Greenland can cause an increase of 2m to 7m,^{32,33} which will severely impact coastal flood risk.³⁴

The dieback of the Amazon and boreal forests are other major tipping points. The forests act as natural carbon sinks and dampen the impact of greenhouse-gas emissions by absorbing atmospheric carbon. A dieback of the forests would lead to the destruction of valuable and sensitive natural ecosystems, amplify global warming and change the regional climate that strongly depends on these large forests.³⁵

Climate conditions have fluctuated naturally over many centuries. When faced with scenarios that cannot be assessed precisely, but where evidence points to risks that are increasing, mankind no longer has the luxury of time to wait till uncertainties become certainties: the time to act is now. By the time data can conclusively show how much hurricane risk increases with each degree of warming, in a world of ever-increasing urban living and economic development, the loss threat posed by hurricanes is only set to grow.

²⁹ E.A. Schuur et al., "Climate change and the permafrost carbon feedback", *Nature*, vol 520, 2015.

³⁰ J.T. Abatzoglou and A.P. Williams, "Impact of anthropogenic climate change on wildfire across western US forests", *Proceedings of the National Academy of Sciences*, 2016.

³¹ T.M. Lenton et al., "Tipping elements in the Earth's climate system", *Proceedings of the National Academy of Sciences*, 2008.

³² T.M. Lenton, "Early warning of climate tipping points", *Nature Climate Change*, vol 1, no 4, 2011.

³³ R.E. Kopp et al., "Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites", *Earth's Future*, vol 2, no 8, 2014.

³⁴ R. Marsooli et al., "Climate change exacerbates hurricane flood hazards along US Atlantic and Gulf Coasts in spatially varying patterns", *Nature Communications*, vol 10, no 1, 2019.

³⁵ S. Solomon et al., "Irreversible climate change due to carbon dioxide emissions", *Proceedings of the National Academy of Sciences*, 2009.

Climate change: implications for insurance

We believe weather-related risks remain insurable. However, to improve risk assessment and ensure insurability in the face of many uncertainties, insurers need to continually adapt their models to changing parameters. In the absence of hard data on climate change effects, they need to incorporate levels of confidence as to expected outcomes across weather variables. Among others, they should track scientific findings, use latest knowledge to de-bias historical records and better understand loss creep, and take location-specific adaptation measures into account to continually update and strengthen their risk models.

A confidence mindset

The risk assessment equation has two new variables: time horizon...

Insurers have traditionally considered natural catastrophe risks with respect to two dimensions: frequency and severity. Climate change has introduced two new complexities to the risk-assessment equation: time horizon and level of confidence. Understanding the timescale of changes to weather systems and the environment due to global warming that have already happened facilitates predictions about future changes. Knowledge of slow and steady changes leaves time for insurers and other stakeholders to adapt and action measures to increase resilience. Building understanding of changes in patterns of extreme weather events is more challenging due to their infrequent occurrence.

...and level of confidence.

In this reality, insurers need to think in different terms when assessing the impact of climate change. In the absence of hard data, the approach should be to assess risk in terms of levels of confidence as to expected outcomes across different weather and environmental variables. With the inherent uncertainties this approach entails, projections should limit the time horizon under consideration. In the face of climate change, the focus for re/insurers and financial regulators should be on the best accurate representation of today's already changing risk landscape and expected changes in the near future.

Confidence is greatest around risks that are directly related to increasing temperatures.

How confident are you?

Figure 9 classifies climate change effects and their relevance for the insurance industry. Confidence about observed and future trends is highest for risks related to the increase in global temperatures. For example, the melting of glaciers and icecaps, and thermal expansion of water in warmer temperatures, are leading to rising sea levels. These can directly increase the magnitude of storm surges, a long-term risk for coastal regions. To date, the rise in sea levels has been relatively slow and will likely remain so in the near future, allowing time for measures to mitigate the risk of coastal flooding. The insurance impact today is limited to the property line of business, and is mostly localised in coastal and flooding zones.

There is also high confidence that climate change has led to increased temperature extremes.

Another outcome of climate change of which there is high confidence is increased temperature extremes, which have brought longer and/or more frequent heat waves, droughts and periods of water scarcity. Heat waves affect agriculture, productivity, infrastructure, water resources, health and mortality. Further, hot and dry conditions exacerbate wildfire risk, as seen in different regions in recent years (eg, California, Portugal and Australia), with severe consequences for exposures in the WUI. Most impacted are primary insurers as losses from frequency perils remain largely within the retentions of their reinsurance programmes. The impact for reinsurers is through proportional covers such as quota shares and/or non-proportional covers such as annual aggregate covers.

There's less confidence to say that climate change has led to increased risk of extreme rainfall and flooding.

Increasing temperatures allow the atmosphere to hold more water vapour, thus (on average) increasing the risk of extreme rainfall (including tropical cyclone-induced rainfall). However, there is less confidence in estimating the impact of increasing temperature on river-flood risk, which is impacted by other factors, too. Regional trends are already observable, but the insurance impact for flood-related losses is limited due to still-large protection gaps in this area. With yet lower confidence is the understanding of trends for atmospheric and oceanographic circulation changes. These affect, for example, the frequency and intensity of tropical cyclones or European winter storms. This is in part due to the to-date low frequency of

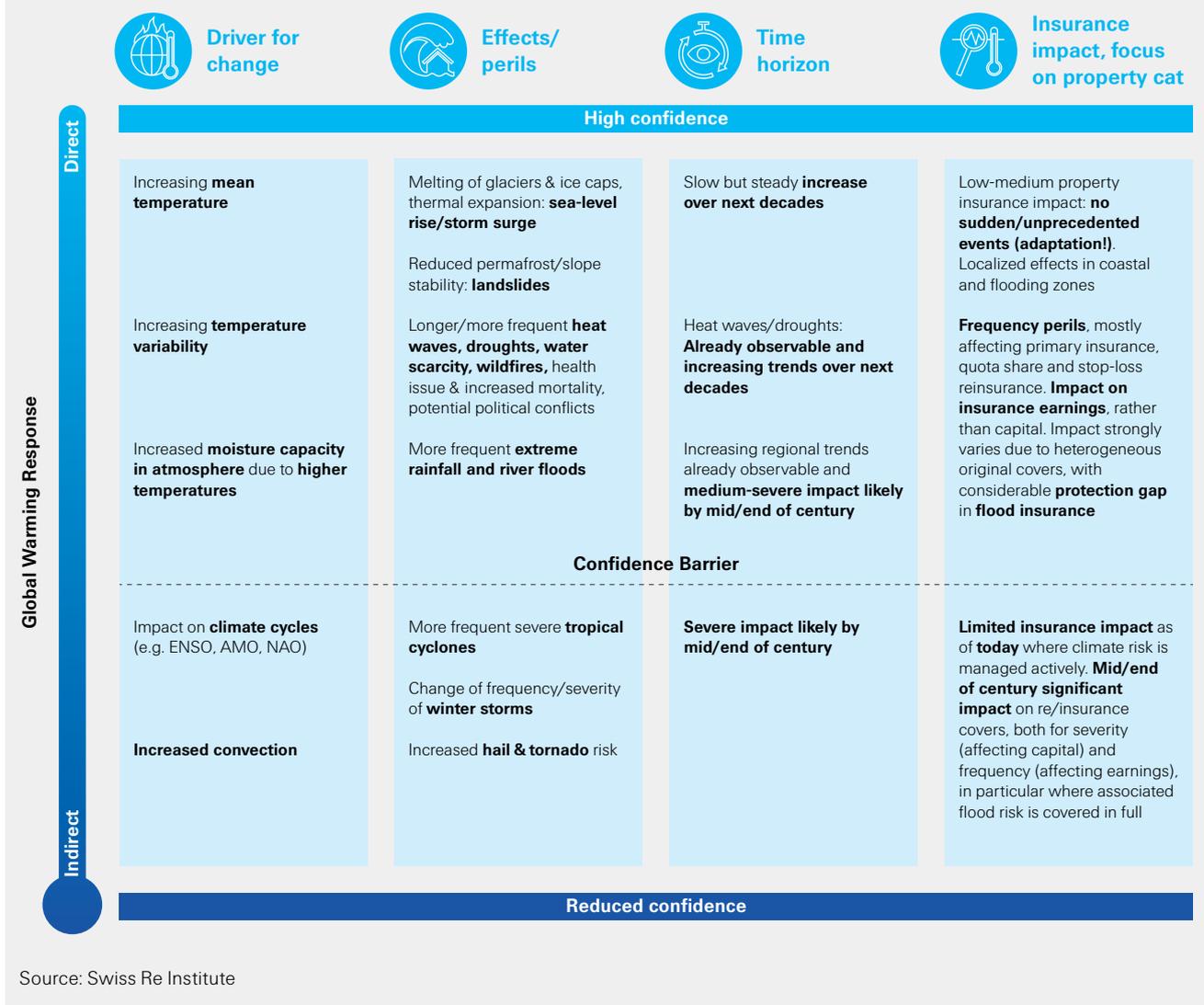
Climate change: implications for insurance

occurrence of such extreme weather events, and because of the complex interplay of the different factors that determine the climate system. While warmer sea-surface temperatures will increase the probability of tropical cyclone formation and intensification, higher wind shear can offset this. At the same time, there is uncertainty about the influence of climate change on jet streams, for instance, and how that will influence extratropical cyclones and impact occurrence of anomalously stationary weather patterns.³⁶ On a global scale, we see potentially high impact on property and business interruption insurance by the mid/end of the century. Already today, localised impact in these lines shows in regions vulnerable to flooding.

To overcome "confidence barriers", more research and advanced modelling is needed.

These complex interactions introduce a "confidence barrier" that render any insurance-related quantification of climate-change effects on high-severity perils like hurricanes very uncertain. Given their material impact, re/insurers and the broader modelling community need to lower this barrier through additional research and quantifying modelling uncertainties in areas where confidence remains low.

Figure 9
Classification of climate-change effects and their relevance for the re/insurance industry



Source: Swiss Re Institute

³⁶ D. Coumou, G. Di Capua, S. Vavrus, L. Wang, S. Wang, "The influence of Arctic amplification on mid-latitude summer circulation," *Nature Communications*, vol 9, no 1, 2018.

Climate change and the business of risk protection

Weather-related perils remain insurable...

We believe weather-related perils remain insurable. While an understanding of the long-term consequences of climate change are essential for mitigation policies and strategic decision-taking, the short-term nature of most (property) re/insurance business allows for continuous adjustments of risk view and risk appetite. These regular adjustments, not only for changes in natural hazards but also for changes in exposures, make climate change a still manageable risk for the re/insurance industry. Nevertheless, careful monitoring of loss developments and risk trends is required to ensure profitability and also solvency in the case of changes to tail risks.

...although the rise in losses from high-frequency secondary perils is challenging this assertion.

Climate change is dynamic and risk assessment needs to track dynamic changes. In recent years, there has been a trend of rising losses resulting from secondary perils, and we expect this to continue as the world gets warmer, likely leading to more occurrence of extreme weather conditions and associated secondary peril events. Both secondary and primary perils can become more frequent and more severe, and models need to be adapted accordingly (dynamically).

The US flood insurance market is one area where dynamic adaptation of models will help avoid mis-pricing on account of climate change effects.

For example the US flood insurance market will likely be impacted by climate change effects on inland (pluvial and fluvial) and coastal (storm surge) flood risk. The area within the Special Flood Hazard Area (the area within the 100-year floodplain where development is restricted under the National Flood Insurance Program (NFIP)) is expected to expand spatially by 40–45% by 2100.³⁷ Assuming a fixed shoreline, we estimate that the average loss cost per policy will increase by 90%, and average premium per policy by 70% by 2100. Projections like these have prompted calls for reforms to the NFIP, including suggestions to account for climate change effects in flood risk mapping, and strategies to encourage migration away from flood-prone areas and expedite the process of bringing buildings into compliance with building regulations (including elevation of homes).³⁸

Climate change effects can hit both sides of re/insurers' balance sheets.

Keeping weather-related perils insurable

Re/insurance companies face many climate-change risks on both sides of their balance sheets.³⁹ The main focus here is on the liability side where physical climate-change risks can impact underwriting results. Furthermore, actions by clients, regulators and other market participants can introduce new risks with potentially adverse effects on profitability as well as solvency considerations.

The main underwriting risk for insurers is to underestimate premiums due to reliance on historical loss data or incomplete/outdated models.

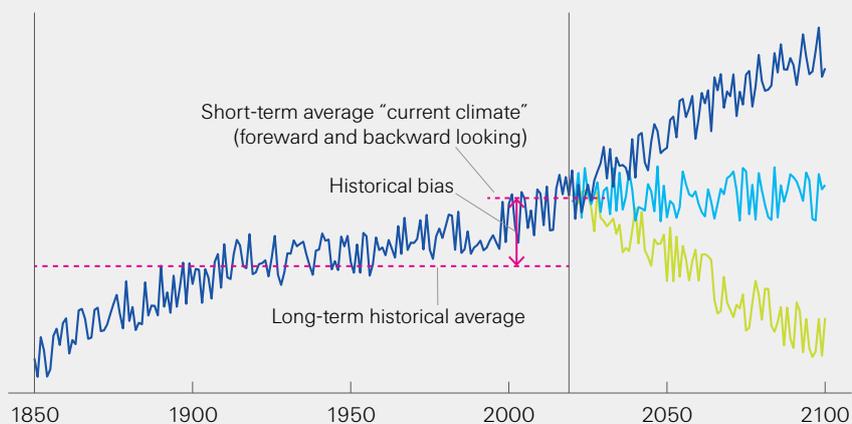
The foremost underwriting risk in the context of climate change and other macro-risk trends is potential underestimation of insurance premiums by relying on historical loss data or incomplete/outdated models to assess the current risk. This is illustrated in Figure 10: if risk assessment is based on a long-term historical average of a physical hazard, a historical bias can create a gap between actual and modelled risk. This is true for both low- and high-frequency perils, potentially leading to risk views that lag the current risk landscape.

³⁷ *The impact of climate change and population growth on the National Flood Insurance Program through 2100*, AECOM, 2013.

³⁸ D. Adler et al., "Changing the National Flood Insurance Program for a changing climate", *Environmental Law Reporter*, vol 49, no 4, 2019.

³⁹ E. Mills, "Insurance in a Climate of Change", *Science*, vol 309, 2005.

Figure 10
Historical modelling bias



Source: Swiss Re Institute

Recommendations

Suggested actions for insurers.

The following actions will help insurers provide cover for climate change-influenced risks, maintain balance sheet strength and thereby support sustainable resilience.

- Track and model for latest scientific findings:** For their business model to be sustainable as the climate changes, insurers need to keep abreast of the latest scientific findings and incorporate them into their natural-catastrophe models. Efforts should be directed at translating scientific results into workable risk-assessment know-how. More sophisticated modelling approaches are needed to account for (the growing loss impacts of) secondary perils that have been inadequately modelled in the past, such as in the case of tropical cyclone risk in Japan (see Typhoon Hagibis: a wake-up call). This is especially important for primary insurers and reinsurance products with annual aggregate covers, where more frequent small-scale events can drastically change the scale of risk.

The typhoon events in Japan of the past two years are a wake-up call.

Typhoon Hagibis: a wake-up call

In 2019, Japan was hit by back-to-back typhoon events: Faxai in September and Hagibis in October. The typhoons caused significant damage in densely populated areas, including the greater Tokyo metropolitan area and Chiba Prefecture. Damage was due to the very strong winds and heavy rains of the typhoons, leading to exceptional inland flooding. Given a long history of typhoons, Faxai and Hagibis, and also Typhoon Prapiroon in 2018 were not "surprise" events, per se. However, Typhoon Hagibis in particular, and also the flooding from Prapiroon the previous year, have put a spotlight on the flood risk potential in Japan.

The insurance industry needs to recalibrate its assessment of the risk that flooding poses in the country.

With huge investment in coastal and inland flood defence following the devastating typhoon events in the 1950s and 1960s, flood risk in Japan was considered to be largely/completely mitigated. Typhoon Hagibis has challenged this assumption: while flood protection measures successfully prevented major havoc in the denser portions of Greater Tokyo, at least 55 levee breaches and overflowing rivers such as in Nagano prefecture illustrated a substantial flood risk only partially mitigated. Out of the USD 8 billion in insured losses, the majority stems from flood losses. Today's flood defences mitigate the impact, but by no means entirely. This calls for a recalibration of models with respect to the higher levels of risk, particularly in terms of intensity, that water inundation in Japan poses today.

- **Incorporate scientific results into risk-assessment and underwriting:** Insurers should better quantify the impact of frequency and severity changes of losses in the coming two to three years, and also better understand how to adjust historical loss experience to design sustainable and suitably priced products for the near future. For example, a line of business highly susceptible to climate change is agriculture: observations, physical theory and numerical modelling all converge to show increased frequencies of heatwaves and agricultural droughts in most parts of the globe.⁴⁰ Severe drought impacts crop yields and earlier starts to the growing cycle can make crops more vulnerable to extreme frost events. Technological advancements like precision farming, land monitoring and better irrigation systems can partly mitigate the impact of climate events on agriculture. When fully accounted for, such developments can be used to challenge and modify the representativeness of historical loss data.
- **De-bias historical records and mitigate loss creep:** Further, the modelling and underwriting communities need to develop better methods to de-bias historical records be it for exposure, hazard and vulnerability. Key is understanding how factors like GDP growth and urbanisation, which are currently not fully captured in risk models, impact rising risk and losses.

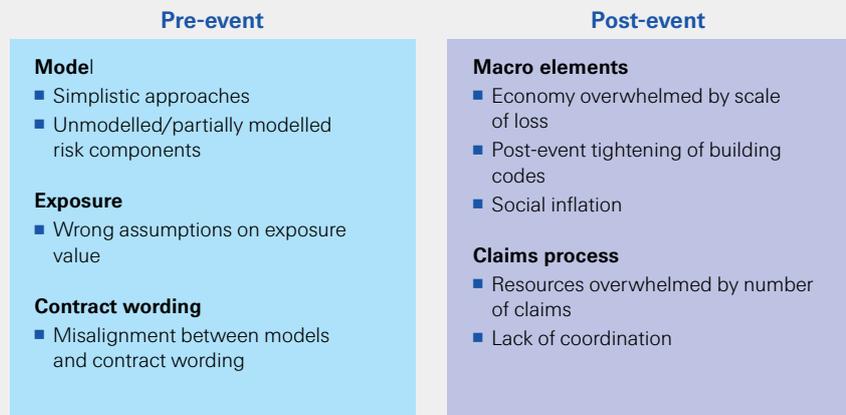
This will also help counteract loss creep. In the case of some recent disaster events such as Typhoon Jebi in Japan in 2018, loss creep was due to unmodelled complex loss components that had nothing to do with climate change, and only partially with urbanisation. Losses from Jebi continued to increase through 2019, with the final tally of close to USD 13 billion more than double the USD 6 billion that catastrophe models had initially estimated.

Figure 11 shows factors that can contribute to adverse loss developments and loss creep. These include:

- Model limitations: These include “known” limitations as direct consequence of simplified approaches used to describe complex phenomena such as secondary perils or post-loss amplification. They also include “unknown” limitations as a result of extreme phenomena that are not fully understood and only partially considered or even ignored in models (eg, climate change effects, changes in land use alongside rising urbanisation).
- Macro and socio-economic effects, such as an economy overwhelmed by scale of loss, lack of preparedness, and social inflation pushing losses higher. For instance, the practice of the Floridian policyholders to transfer their insurance claims to third parties like home-improvement contractors and lawyers (so called Assignment of Benefits, AOB), has become a significant driver of property claims escalation. In Florida, AOB abuse and a proliferation of litigation is estimated to have increased the insured losses resulting from Hurricane Irma in 2017 by more than 20%.
- Wrong assumptions on exposure data, like underestimating reconstruction costs. This was the case in the 2010/2011 New Zealand earthquakes, where the replacement costs were almost three times higher than the insured value indicated in the policies.
- The wording of an insurance policy or reinsurance terms, such as insufficient underinsurance provisions, and misalignment between models and wording (eg, land damage/restoration covered or not properly addressed).
- Complicated claims process due to lack of coordination between various players, or presence of multiple policies on the same claim.

⁴⁰ *Special Report on Climate Change and Land*, IPCC, 2019.

Figure 11
Components of loss creep



Source: Swiss Re Institute

- **Take account of local-specific risk mitigation and adaptation measures:** To improve pricing, insurers should also take into consideration the effectiveness of local mitigation and adaptation measures. For example, managing flood risk from rising sea levels in Rotterdam in the Netherlands is very different from Beira in Mozambique. Both cities are in low-lying areas but also in countries with very different national climate change adaptation policies. The Netherlands is a giant delta with a long history of mitigating flood risk with a system of dykes, dunes, dams and barriers. Faced with rising sea and rainfall levels, in recent years the Dutch government has reformulated its policies on flood protection moving from a focus on reducing the hazard to a more comprehensive risk-based and adaptive approach. A wide range of adaptation measures based on both water management and sustainable spatial planning have been devised. In addition, climate risk is continuously assessed, and the policy is redefined as new scientific findings about an evolving physical risk landscape and the impact on flood risk become available.⁴¹

The opposite is the case in Mozambique, where there has been lack of planning and investment in flood-risk mitigation measures. As a result, when Cyclone Idai made landfall in March 2019, heavy precipitation and storm surge was able to flood 90% of the city of Beira, including some of the country’s most fertile agricultural lands just prior to harvest.⁴² The total economic loss from Idai was USD 3 billion, the costliest catastrophe to hit Mozambique and the costliest weather event in Africa on sigma records. Insurance cover was just USD 150 million. Six weeks later, an even stronger cyclone, Cyclone Kenneth, made landfall along the border of Mozambique and Tanzania, leaving close to 2 million people homeless.

- **Monitor changing claims patterns:** Insurers should improve detection and understanding of changing claims patterns. It is essential to increase granularity in claims reporting to analyse the drivers for new trends, as climate change effects manifest over various time scales and with regional characteristics. Failing to detect trends and to adjust risk premiums will affect sustainability of the insurance risk transfer model.

⁴¹ For more on these developments, see *Climate change adaptation: lessons from the Dutch masters* in the Europe edition of our additional sigma 2/2020 extra series produced to compliment this main report. The series is available from the Swiss Re Institute website.

⁴² A. Schroeder, "Rethinking disaster preparedness in Southern Africa after Cyclone Idai", *PreventionWeb.net*, 9 April 2019.

- **Respond to the rising public awareness of climate change:** To respond to changing customer needs, insurers should not only offer innovative insurance covers but also share their risk expertise as an advisory service for clients.
- **Apply environmental, social and governance (ESG) criteria to investment activities:** On the asset side, insurers should apply ESG criteria to their investment activities (and also in underwriting). As long-term investors, global re/insurers can advocate for better disclosure in financial reporting and promote financial securitisation for infrastructure as a tradable asset class, according to the Principles of Responsible Investing. In addition, by embedding insurance into climate-resilient infrastructure projects, they can facilitate financing by collaborating with multilateral banks and government agencies.
- **Engage with regulators:** Climate change has become a growing concern for financial regulators, and transition to a low-carbon economy will remain a key political objective. Sustainability has been incorporated into prudential and conduct regulation across the financial sector, with the main focus on stress tests and scenario analysis.

We anticipate considerable development in regulatory requirements and guidance over the next couple of years, in particular with regards to scenario testing, as transition to a low-carbon economy remains a key political objective across various jurisdictions. Active dialogue by insurers with regulators is key to steer the discussion: (1) to where it matters for P&C insurers (versus financial firms in general); and (2) to create a level playing field where the incorporation of macro risk trends becomes not an art for the most advanced players, but a necessity for the insurance industry as a whole.

Conclusion

Climate change effects are showing, but it's too soon to make a definitive link to rising weather risk losses.

The main driver of rising losses resulting from weather-related events remains exposure accumulation.

No need to panic, but the time to act is now.

The risk landscape is dynamic and insurers need to respond accordingly with continual adaptations of their risk models...

...while also taking stock of existing underwriting processes.

After two costly back-to-back years for natural catastrophes in 2017 and 2018, insured losses declined in 2019 due to the lack of severe hurricanes in the US. With respect to a contribution from climate change, we believe warmer temperatures, rising sea levels, and longer and more frequent heatwaves all signal that climate change is real. We expect these changes will continue as the world gets warmer, leading to more frequent occurrence of extreme weather events. These, in turn, will likely lead to rising losses, particularly from associated secondary peril events.

What does this mean for insurers? In this report, we demonstrate that the main driver of the trend of rising losses resulting from weather events over the years has been accumulation of exposures, due to economic growth and urbanisation. Other socio-economic factors further influence loss trends and as such, climate change as a contributing component is (will be) one of many.

Nevertheless, re/insurers should not take climate risks lightly. The most immediate impact climate change effects can have is to amplify the exposures from ongoing urbanisation and concentration of assets, particularly when urban sprawl spreads into high-risk zones like low-lying coastal areas. Proximity amplifies the loss potential from weather-related events by increasing the number of people and assets exposed, particularly when risk mitigation measures do not keep pace with the rise in value accumulation. On the liability side of their balance sheets, the main threat to insurers' profitability is the subsequent increase in claims. On the asset side, the threat posed by climate change comes in the form of physical risks to insurers' invested assets and transition risks as the world moves to a zero-carbon economy.

We believe weather-related risks remain insurable, but the time to act is now. The long-term risk of unmitigated climate change is irreversible "tipping points" in climate systems. In this scenario, increased frequency and intensity of weather-related events, and also unforeseen changes in climate conditions and socio-economic developments, could bring the insurability of assets, particularly in highly exposed regions, into question. The risk landscape is dynamic and to avoid falling behind the curve, insurers need to actively track socio-economic developments, scientific findings as to climate change effects, and the status of local risk mitigation measures in order to keep weather risks insurable. As an ongoing adaptation exercise, they need to embed this knowledge in continual risk assessment updates, so that their models represent present-day climate change and socio-economic circumstances.

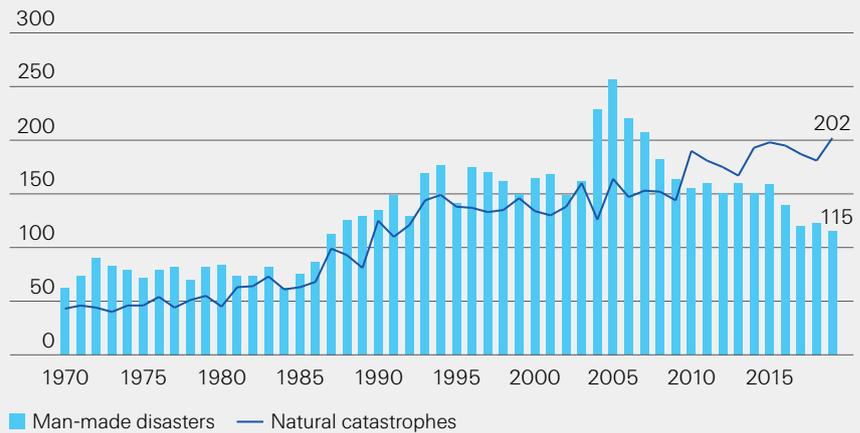
Further, the main underwriting risk facing insurers is underestimation of insurance risk premiums due to reliance on historical loss data or incomplete/outdated models. To this end, insurers should take stock of their underwriting processes, using latest knowledge to de-bias historical records and better understand loss creep and incorporate previously not-considered loss components in their risk assessment.

Facts and figures

Number of events: 317

In terms of sigma criteria, there were 317 catastrophes worldwide in 2019, up from 304 in 2018. There were 202 natural catastrophes (up from 181 in 2018), the highest ever recorded, and 115 man-made disasters (down from 123 in 2018).

Figure 12
Number of catastrophic events, 1970–2019



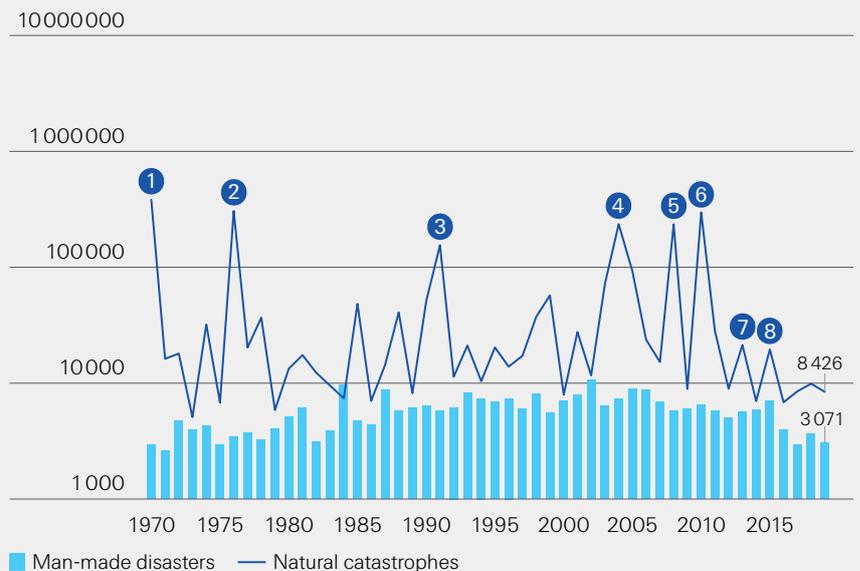
Source: Swiss Re Institute

Number of victims: close to 11 500

Worldwide, 11 497 people are believed to have died or gone missing in disaster events in 2019, one of the lowest ever in a single year on *sigma* records. Natural catastrophes claimed more than 8000 victims, and man-made disasters over 3000.

Figure 13
Number of victims, 1970–2019

1. 1970: Bangladesh storm, Peru earthquake
2. 1976: Tangshan earthquake, China
3. 1991: Cyclone Gorky, Bangladesh
4. 2004: Indian Ocean earthquake and tsunami
5. 2008: Cyclone Nargis, Myanmar
6. 2010: Haiti earthquake
7. 2013: Typhoon Haiyan, Philippines
8. 2015: Earthquake in Nepal



Note: Scale is logarithmic: the number of victims increases tenfold per band.

Source: Swiss Re Institute

Total economic losses: USD 146 billion

Total economic losses from disasters across the globe were an estimated USD 146 billion in 2019, down from USD 176 in 2018, with around USD 137 billion resulting from natural catastrophes and the remainder from man-made events.

Table 2
Economic losses, in USD billion and as a % of global GDP, 2018

Regions	in USD bn*	in % of GDP
North America	45	0.19%
Latin America & Caribbean	12	0.23%
Europe	14	0.06%
Africa	5	0.22%
Asia	66	0.21%
Oceania/Australia	4	0.25%
Seas / Space	0	0.00%
Total	146	
World average		0.17%
10-y average**	212	0.26%

*rounded numbers
**inflation adjusted

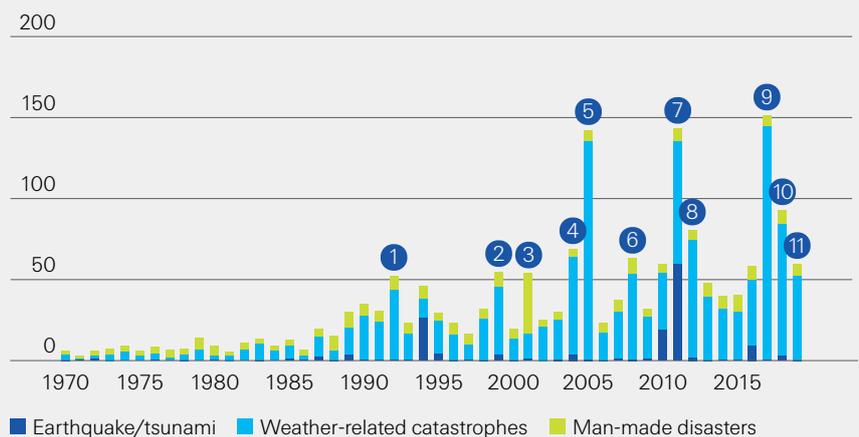
Source: Swiss Re Institute

Insured losses: USD 60 billion

Global insured losses were USD 59 billion, down from USD 93 billion in 2018 and below the annual average (USD 75 billion) of the previous 10 years. Of these, natural catastrophes resulted in USD 52 billion, down from USD 81 in 2018. Man-made disaster events triggered additional claims for USD 8 billion, down from USD 9 billion in 2018.

Figure 14
Insured catastrophe losses, 1970–2019, in USD billion at 2019 prices

1. Hurricane Andrew
2. Winter Storm Lothar
3. WTC
4. Hurricanes Ivan, Charley, Frances
5. Hurricanes Katrina, Rita, Wilma
6. Hurricanes Ike, Gustav
7. Japan, NZ earthquakes, Thailand flood
8. Hurricane Sandy
9. Hurricanes Harvey, Irma, Maria
10. Camp Fire, Typhoon Jebi
11. Typhoons Hagibis, Faxai

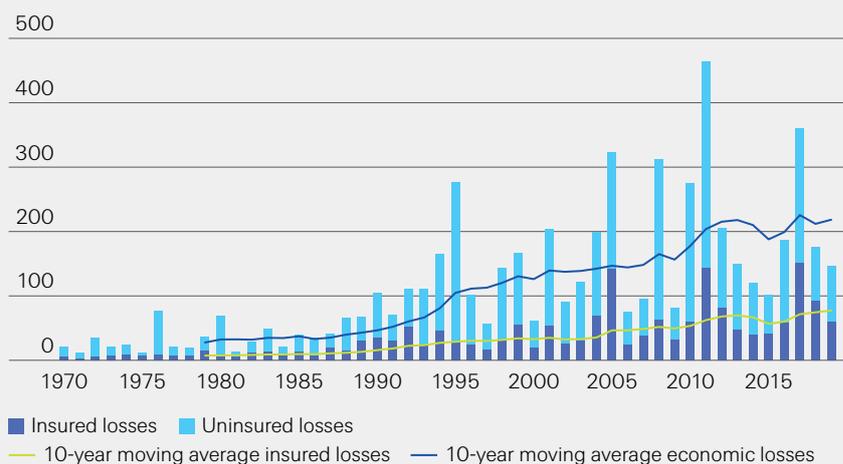


Source: Swiss Re Institute

Global catastrophe protection gap: USD 86 billion

Figure 15 shows the difference between economic and insured losses over time, the insurance protection gap. It is the financial loss generated by catastrophes not covered by insurance. In 2019, the global protection gap was around USD 86 billion, up from USD 83 billion in 2018, but down from the 10-year average of USD 137 billion.

Figure 15
Insured vs uninsured losses,
1970–2019
(USD billion, 2019 prices)



Economic losses = insured + uninsured losses;

Source: Swiss Re Institute

Regional loss overview

Insured and economic losses were highest in North America and Asia.

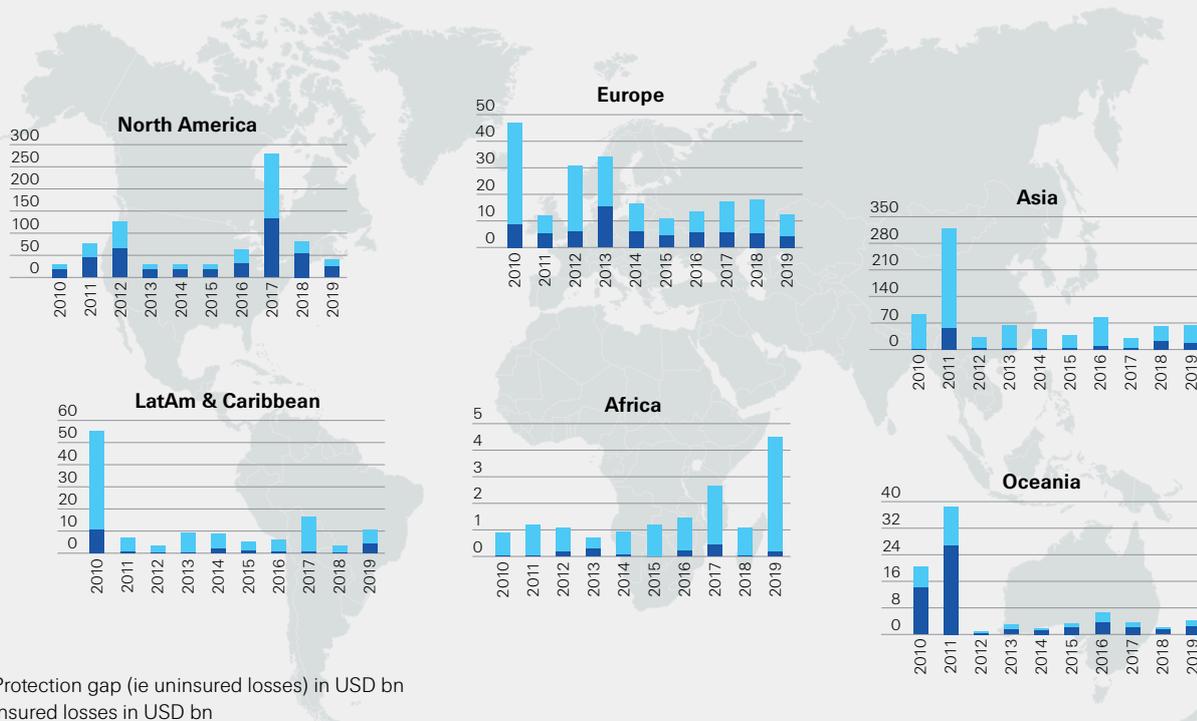
Table 3
Number of events, victims, economic and insured losses by region, 2019

Region	Number	Victims	in %	Insured losses		Economic losses	
				in USD bn	in %	in USD bn	in %
North America	87	212	1.8%	27.2	45.6%	44.7	30.6%
Latin America & Caribbean	20	964	8.4%	5.2	8.7%	11.9	8.2%
Europe	45	328	2.9%	5.4	9.0%	13.6	9.3%
Africa	54	3332	29.0%	0.8	1.4%	5.3	3.6%
Asia	102	6546	56.9%	18.3	30.6%	65.9	45.1%
Oceania/Australia	5	77	0.7%	2.5	4.1%	4.1	2.8%
Seas/ Space	4	38	0.3%	0.4	0.7%	0.4	0.3%
World	317	11497	100.0%	60	100.0%	146	100.0%

Note: some percentages may not add up to 100 due to rounding

Source: Swiss Re Institute

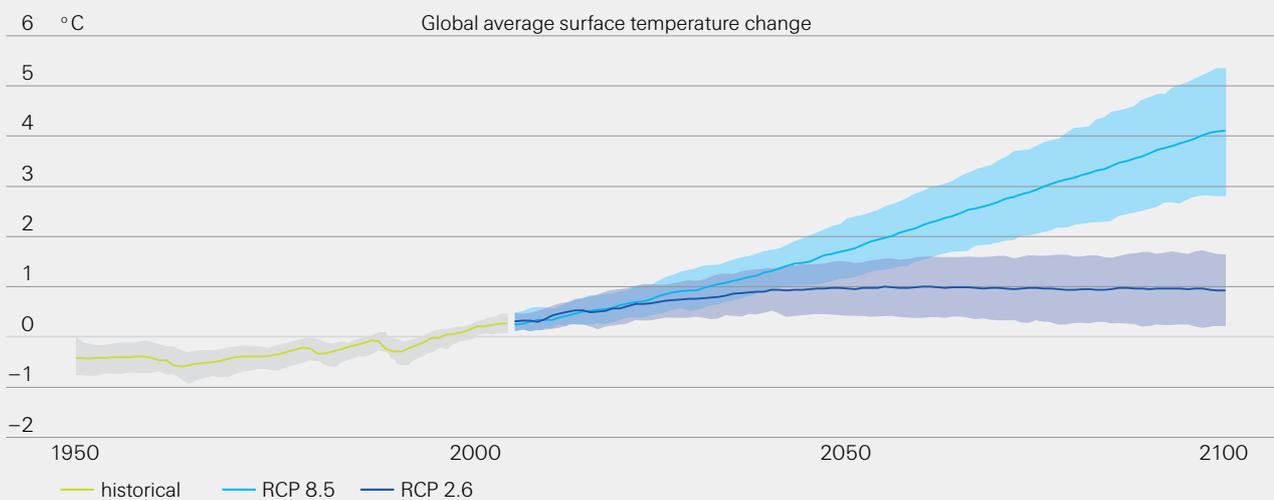
Figure 16:
Natural catastrophes protection gap by region 2010–2019 (USD billion, 2019 prices)



Note: Economic losses = Insured losses + Uninsured losses
 Source: Swiss Re Institute

Representative Concentration Pathways (RCP)

The figure below indicates the expected future increase of average surface temperatures for different RCP, which are possible future trajectories of greenhouse-gas-induced radiative forcing. Scenarios range from lower RCP2.6 to higher RCP8.5, which is the “business-as-usual scenario” if no mitigation and adaptation measures are put in place to contain the temperature increase.



Source: IPCC

Definition of terms and selection criteria

A natural catastrophe is caused by natural forces.

Natural catastrophes

The term “natural catastrophe” refers to an event caused by natural forces. Such an event generally results in a large number of individual losses involving many insurance policies. The scale of the losses resulting from a catastrophe depends not only on the severity of the natural forces concerned, but also on man-made factors, such as building design or the efficiency of disaster control in the afflicted region. In this *sigma* study, natural catastrophes are subdivided into the following categories: floods, storms, earthquakes, droughts/forest fires/heat waves, cold waves/frost, hail, tsunamis, and other natural catastrophes.

A man-made or technical disaster is triggered by human activities.

Man-made disasters

This study categorises major events associated with human activities as “man-made” or “technical” disasters. Generally, a large object in a very limited space is affected, which is covered by a small number of insurance policies. War, civil war, and war-like events are excluded. *sigma* subdivides man-made disasters into the following categories: major fires and explosions, aviation and space disasters, shipping disasters, rail disasters, mining accidents, collapse of buildings/bridges, and miscellaneous (including terrorism).

Losses due to property damage and business interruption that are directly attributable to major events are included in this study.

Economic losses

For the purposes of the present *sigma* study, economic losses are all the financial losses directly attributable to a major event, ie damage to buildings, infrastructure, vehicles etc. The term also includes losses due to business interruption as a direct consequence of the property damage. Insured losses are gross of any reinsurance, be it provided by commercial or government schemes. A figure identified as “total damage” or “economic loss” includes all damage, insured and uninsured. Total loss figures do not include indirect financial losses – ie loss of earnings by suppliers due to disabled businesses, estimated shortfalls in GDP and non-economic losses, such as loss of reputation or impaired quality of life.

The amount of the economic losses is a general indication only.

Generally, total (or economic) losses are estimated and communicated in very different ways. As a result, they are not directly comparable and should be seen only as an indication of the general order of magnitude.

The term “losses” refer to insured losses, but do not include liability.

Insured losses

“Losses” refer to all insured losses except liability. Leaving aside liability losses, on one hand, allows a relatively swift assessment of the insurance year; on the other hand, however, it tends to understate the cost of man-made disasters. Life insurance losses are also not included.

NFIP flood damage in the US is included.

NFIP flood damage in the US

The *sigma* catastrophe database also includes flood damage covered by the National Flood Insurance Program (NFIP) in the US, provided that it fulfils the *sigma* selection criteria.

Losses are determined using year-end exchange rates and are then adjusted for inflation.

Adjustment for inflation, changes to published data, information

sigma converts all losses for the occurrence year not given in USD into USD using the end-of-year exchange rate. To adjust for inflation, these USD values are extrapolated using the US consumer price index to give current (2019) values.

This can be illustrated by examining the insured property losses arising from the floods which occurred in the UK between 29 October and 10 November 2000:

Insured loss at 2000 prices: USD 1046.5 million

Insured loss at 2019 prices: USD 1553.6 million

Figure 17
Alternative methods of adjusting for inflation, by comparison

Floods UK 29 October–10 November 2000	Exchange rate		US inflation	
	GBPm	USD/GBP	USDm	USDm
Original loss	700.0	1.495	1046.5	1046.5
Level of consumer price index 2000	72.7			72.7
Level of consumer price index 2019	107.8			107.9
Inflation factor	1.483			1.485
Adjusted for inflation to 2019	1038.1	1.321	1371.3	1553.6
Comparison			88%	100%

Source: Swiss Re Institute

Alternatively, were one to adjust the losses in the original currency (GBP) for inflation and then convert them to USD using the current exchange rate, one would end up with an insured loss at 2019 prices of USD 1371.3 million, 12% less than with the standard sigma method. The reason for the difference is that the value of the GBP declined by almost 12% against the USD in the period 2000–2019. The difference in inflation between the US (45.8%) and the UK (45.7%) over the same period was negligible.

For the 2019 reporting year, the lower loss thresholds were set as follows:

Insured losses (claims):

Maritime disasters	USD 21.2 million
Aviation	USD 42.4 million
Other losses	USD 52.7 million
<i>or</i> Total economic losses:	USD 105.4 million
<i>or</i> Casualties	
Dead or missing	20
Injured	50
Homeless	2000

Thresholds for financial losses and casualties in 2019

Changes to loss amounts of previously published events are updated in the *sigma* database.

If changes to the loss amounts of previously published events become known, *sigma* takes these into account in its database, but Swiss Re is under no obligation to publicly revise or update this *sigma* study.

Newspapers, direct insurance and reinsurance periodicals, specialist publications and other reports are used to compile this study.

Sources

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Published by

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The editorial deadline for this study was 17 March 2020.

sigma is available on Swiss Re's website:
www.swissre.com/sigma

The internet version may contain slightly updated information.

Translations:
Spanish: Traductores Asociados Valencia S.L.

Graphic design and production:
Corporate Real Estate & Logistics / Media Production, Zurich



Printing: Multicolor Print AG, Baar

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Order no: 270_0220_EN

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